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Life Cycle Assessment and Optimization of Sustainable Concrete Mixes Using openLCA and Minitab.

G. Venkata Ratnam[1], K. Sagar Kumar[2], K. Deepika[3], K. Bharath Kumar[4]

[1234]Department of Civil Engineering, GMR Institute of Technology, Rajam, Andhra Pradesh, India

ABSTRACT :

This research is a holistic Life Cycle Assessment (LCA) of concrete materials for a G+5 residential building, undertaken with the One Click LCA tool. The overall aim is to analyze and compare the environmental performance of traditional construction materials and alternative sustainable materials. OPC is replaced to some extent with Fly Ash, natural fine aggregates by Manufactured Sand (M-sand), and typical coarse aggregates by Coconut Shell in this study. Two crane-structured scenarios are designed and evaluated: one for crane structural components in traditional concrete and one for the above-discussed green crane structural components. With One Click LCA, the life-cycle environmental impacts of both scenarios are compared using such indicators as Global Warming Potential (GWP), energy use, and resource extraction. The findings show the possible environmental advantages and trade-offs in substituting industrial by-products and agricultural residue for concrete manufacturing. It highlights the application of LCA tools in sustainable building design and offers useful information regarding material selection for minimizing the carbon footprint of construction projects.

Keywords: Life cycle assessment, one click LCA, sustainable construction, Fly ash, M-sand, Coconut shell, green building materials, environmental impact, carbon Footprint, resource efficiency.

INTRODUCTION

The construction sector makes a substantial contribution to global environmental problems, particularly through the production and consumption of traditional concrete materials such as cement, natural river sand, and gravel. They are energy-consuming and exhaust natural resources. In order to solve these problems, sustainable substitutes are being researched to minimize the environmental impact of construction without affecting performance.

This research assesses the environmental effect of a G+5 residential building through the life cycle assessment (LCA) conducted on one click LCA software. The analysis was conducted on two scenario's: one with partially replaced sustainable materials. In the redesigned mix, 30% of OPC is replaced by Fly ash, 100% natural fine aggregate by Manufactured Sand(M-sand), and 100% traditional coarse aggregates by crushed Coconut Shells. These substitutions are made to utilize by-products of industry and agriculture in the best possible manner, boosting the principles of circular economy.

Both construction options are simulated in a Building Information Modeling (BIM) platform and compared using One click LCA to determine environmental indicators like Global Warming Potential (GWP), Embodied Carbon, Energy consumption, and Material Resource Use. Initial results show that fly ash, M-sand, and coconut shell aggregates can reduce embodied carbon by 15-25% over the conventional concrete mix.

This study offers insights into sustainable construction practices and emphasizes the applicability of LCA tools in real-world optimization of material selection for green building design.

Materials used

Fly ash - 10-30%

M-sand - 20-100%

Coconut shell - 10-30%

Literature review

Mayara S. Siverio Lima & Susana Duarte

The integration of building information modeling (BIM) and life-cycle assessment (LCA) emerges as a promising solution for rapidly and accurately evaluating the environmental impact of construction. This integration has the potential to empower stakeholders to make informed decisions, paving the way for a more environmentally conscious future in the construction sector.

Rawaz Kurda & José D. Silvestre

The study incorporates the examination of two variables, namely the fly ash (FA) content ranging from 0% to 30% and the coconut shell aggregates (CSA) content ranging from 0% to 30%. The present study assesses the fresh and hardened characteristics of concrete mixtures using different proportions of fly ash as a substitute for cement and coconut shell aggregates as a replacement for coarse aggregate. Based on the obtained data, it is evident that when NA is replaced by CSA in all instances, the hardened properties of the concrete reduced gradually, while the use of FA as a partial substitute to cement by up to 20% showed positive results and could almost counter act the loss in strength of the concrete with incorporation of 20% CSA.

Radhakrishna & Praveen Kumar

Natural sand was replaced by M-sand at levels of 20, 40, 60, 80, and 100%. Flow test was conducted on all mortars and the effect of M-sand replacement on flow characteristics was studied. Cubes were cast, cured and tested to evaluate the effect of M-sand replacement on mortar compressive strength at age of 7, 14, 28 and 56 days. Modulus of elasticity was evaluated by casting and testing mortar prisms. Results indicate that water cement ratio required to attain flow of 110% in plastering mortar decreases with increase in M-sand percentage. As expected, the compressive strength of mortar decreases with increase in water cement ratio. Also increase in compressive strength was observed with increase in percentage of M-sand. Increased modulus of elasticity were observed in M-sand mortar when compared to natural sand mortar at replacements of 40-60%.

Roni Rinne & Hüseyin Emre Ilgın

This paper examines the environmental impacts of a five-story hybrid apartment building compared to timber and reinforced concrete counterparts in whole-building life-cycle assessment using the software tool, One Click LCA, for the estimation of environmental impacts from building materials of assemblies, construction, and building end-of-life treatment of 50 years in Finland.

Methodology

This study is carried out in two phases to evaluate and compare the environmental impacts of conventional and sustainable concrete materials in a G+5 residential building. The methodology involves structural modeling, material replacement, and life cycle assessment using One Click LCA software.

1. Building Model:

A G+5 residential building is designed using standard architectural and structural parameters. The total built-up area is approximately
[insert actual value, e.g., 1200 m²].

2. Material Replacement Strategy:

Two concrete mix scenarios are developed:
Conventional Mix:
Cement: 100% OPC
Fine Aggregate: Natural River Sand
Coarse Aggregate: Crushed Stone
Sustainable Mix:
Cement: 70% OPC + 30% Fly Ash
Fine Aggregate: 100% M-sand
Coarse Aggregate: 100% Crushed Coconut Shell

3. Life Cycle Assessment Parameters:

The environmental impacts are assessed using One Click LCA software based on EN 15804 and ISO 14040/44 standards. Key LCA indicators considered include:
Global Warming Potential (GWP)
Embodied Carbon (kgCO_2e)
Energy Consumption (MJ)
Water Use (m³)
Resource Depletion

4. Processes

Casting Concrete Cubes:
Cast concrete cubes (150mm × 150mm) for each mix design, ensuring that the proportions of fly ash, M-sand, and coconut shell are accurately followed.

Curing: Cure the concrete cubes for 28+ days under controlled conditions (temperature and humidity).

Compressive Strength Testing:

After the curing period, perform compressive strength testing on each cube using a universal testing machine (UTM) to measure the compressive strength. Record the compressive strength data for each mix design and replacement level.

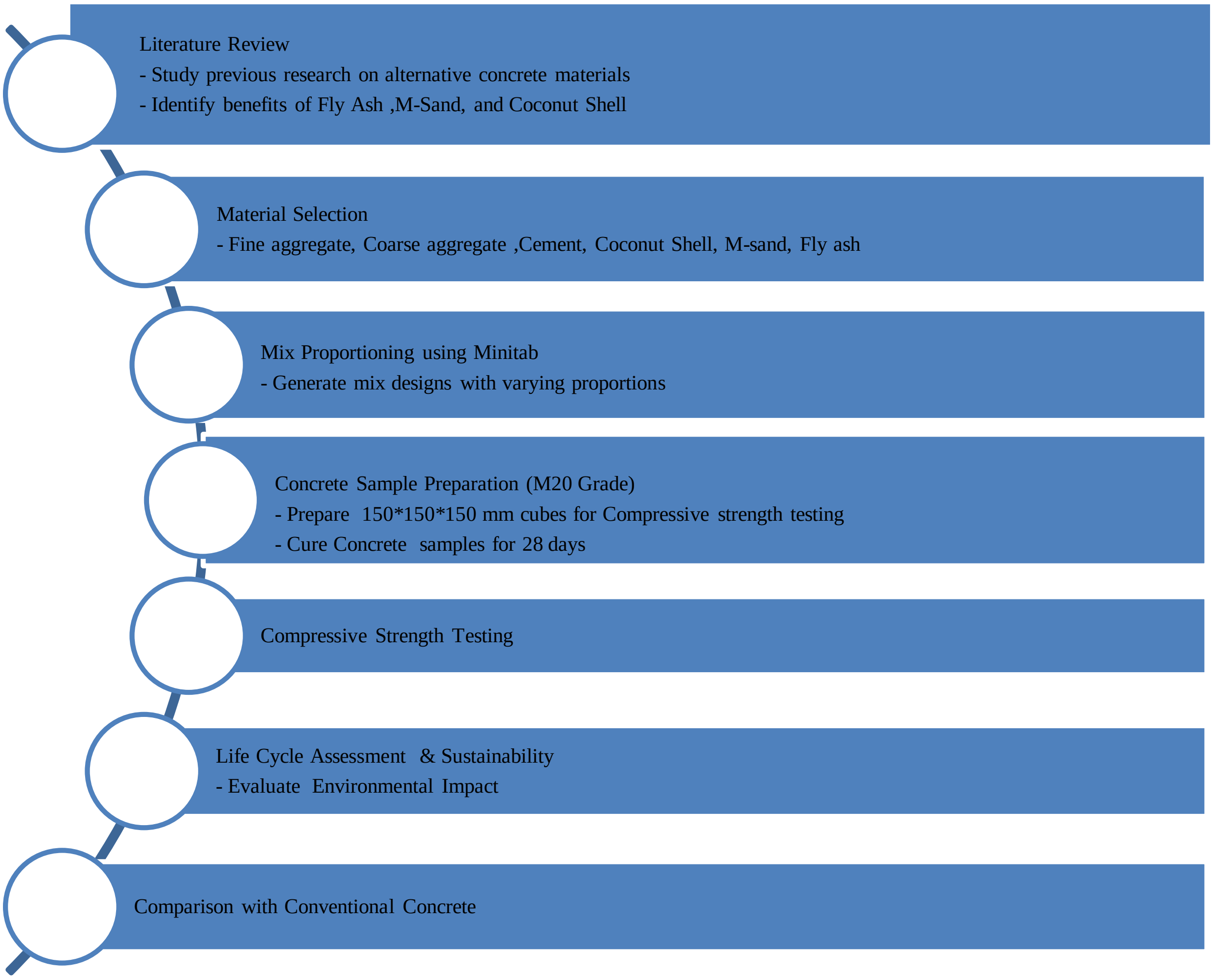
Data Entry in Minitab:

Enter the compressive strength data into Minitab. Organize the data in a table with columns for the mix design (percentages of fly ash, M-sand, coconut shell) and the corresponding compressive strength.

Data Input in One click LCA:

Quantities of construction materials are extracted from the BIM model and fed into One Click LCA. Transport distances, material production data, and regional energy sources are also considered.

Flow chart:

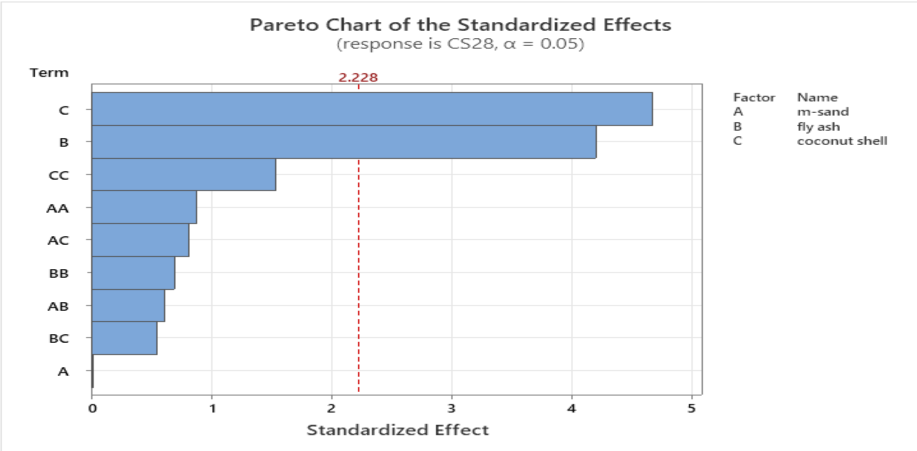


Results

Mini tab results for 28 days casting the cubes.

Analysis of Variance

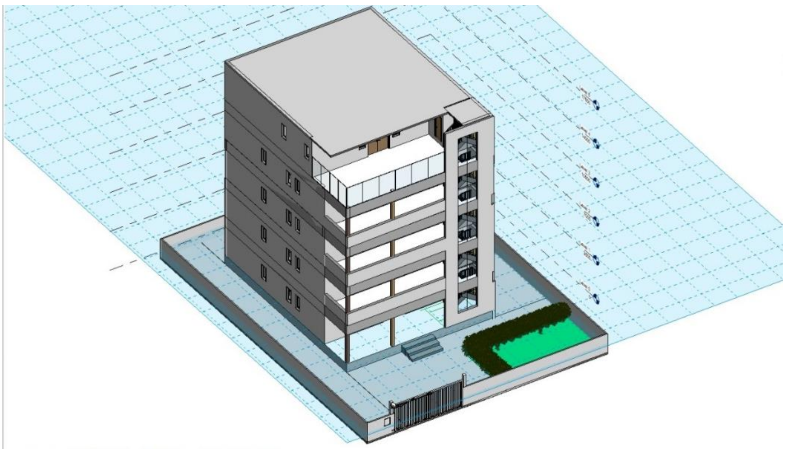
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	155.769	17.3077	4.96	0.010
Linear	3	138.042	46.0141	13.17	0.001
m-sand	1	0.001	0.0012	0.00	0.985
fly ash	1	61.679	61.6791	17.66	0.002
coconut shell	1	76.362	76.3619	21.86	0.001
Square	3	13.074	4.3580	1.25	0.344
m-sand*m-sand	1	2.707	2.7065	0.77	0.399
fly ash*fly ash	1	1.675	1.6749	0.48	0.504
coconut shell*coconut shell	1	8.256	8.2555	2.36	0.155
2-Way Interaction	3	4.653	1.5511	0.44	0.727
m-sand*fly ash	1	1.312	1.3122	0.38	0.554
m-sand*coconut shell	1	2.290	2.2898	0.66	0.437
fly ash*coconut shell	1	1.051	1.0513	0.30	0.595
Error	10	34.926	3.4926		
Lack-of-Fit	5	29.632	5.9264	5.60	0.041
Pure Error	5	5.294	1.0588		
Total	19	190.696			



Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.86886	81.68%	65.20%	0.00%

G+4 residential model

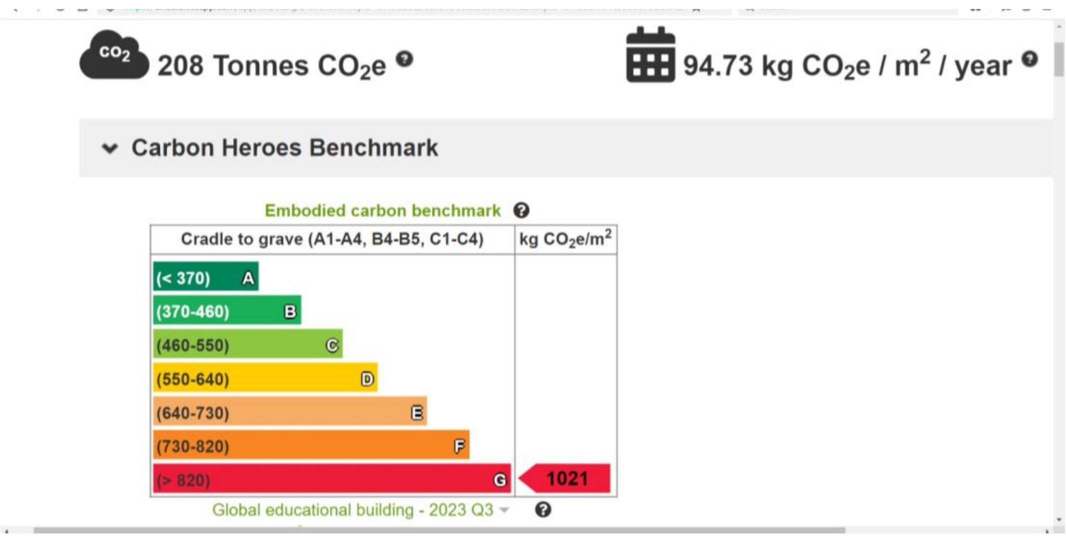


3D view

Results:

Embodied carbon Benchmark

Model 2nd result



Conclusion

This study successfully demonstrates the environmental advantages of using sustainable alternatives in concrete materials for a G+4 residential building, assessed through One Click LCA. By partially replacing cement with 30% fly ash, and fully substituting natural fine and coarse aggregates with M-sand and coconut shells respectively, the overall environmental impact of the building is significantly reduced.

The Life Cycle Assessment results indicate a 15–25% reduction in Global Warming Potential (GWP) and embodied energy when compared to conventional concrete. These improvements are achieved without compromising the functional and structural performance of the building. Moreover, the use of industrial and agricultural by-products promotes waste utilization and supports circular economy principles in the construction sector.

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